A Report on the evaluation of

PAVEMENT DEFLECTION DATA AT THE LONG-TERM MONITORING SITES IN IDAHO FOR STRUCTURAL PERFORMANCE

Final Research Report

Project #128-K028

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INTRODUCTION

This final report presents the results of the evaluation of the Dynaflect deflections measured on asphalt concrete pavements at the Long Term Monitoring sites in Idaho. A brief discussion of cross-slab deflections for portland cement concrete pavements is also presented. The study was intended to seek possible correlations between deflections and surface cracking. A previous report presented our findings for a similar evaluation for the portland cement concrete pavements. This report will provide details about the methodology, a discussion of the results followed by conclusions and recommendations for future research.

The Long Term Monitoring Program (LTM) was developed by the Federal Highway Administration (FHWA) to produce a data base for the evaluation of existing design methods and the development of design procedures for pavement rehabilitation. Idaho, and several other states, participated in this program and have collected high quality data at several sites. The data base was structured to include all variables that, at that time, were thought to be significant in predicting pavement distress, performance, maintenance, and rehabilitation requirements. Figure 1 shows the approximate locations and the site reference numbers of the LTM test sites in Idaho. Each site is one mile long and is divided into 10 subsections. The sites are identified in more detail in Table 1 below:

Table 1, Idaho LTM Data Collection Sites

SITE NUMBER	PAVEMENT SURFACE	LOCATION
160001	PCC	I-90, Huetter
160002	PCC	I-90, Mullan
160003	PCC	US 95, Cottonwood
160004	AC	US 95, Slate Cr.
160005	AC	US 95, Mesa
160006	PCC	I-84, Mtn. Home
160007	PCC	I-84, Pasa. Valley
160008	AC	I-84, Bliss
160009	AC	I-84, Sublett
160010	AC	I-86, Pocatello
160011	PCC	US 20, Rigby
160012	AC	US 20, St. Anthony

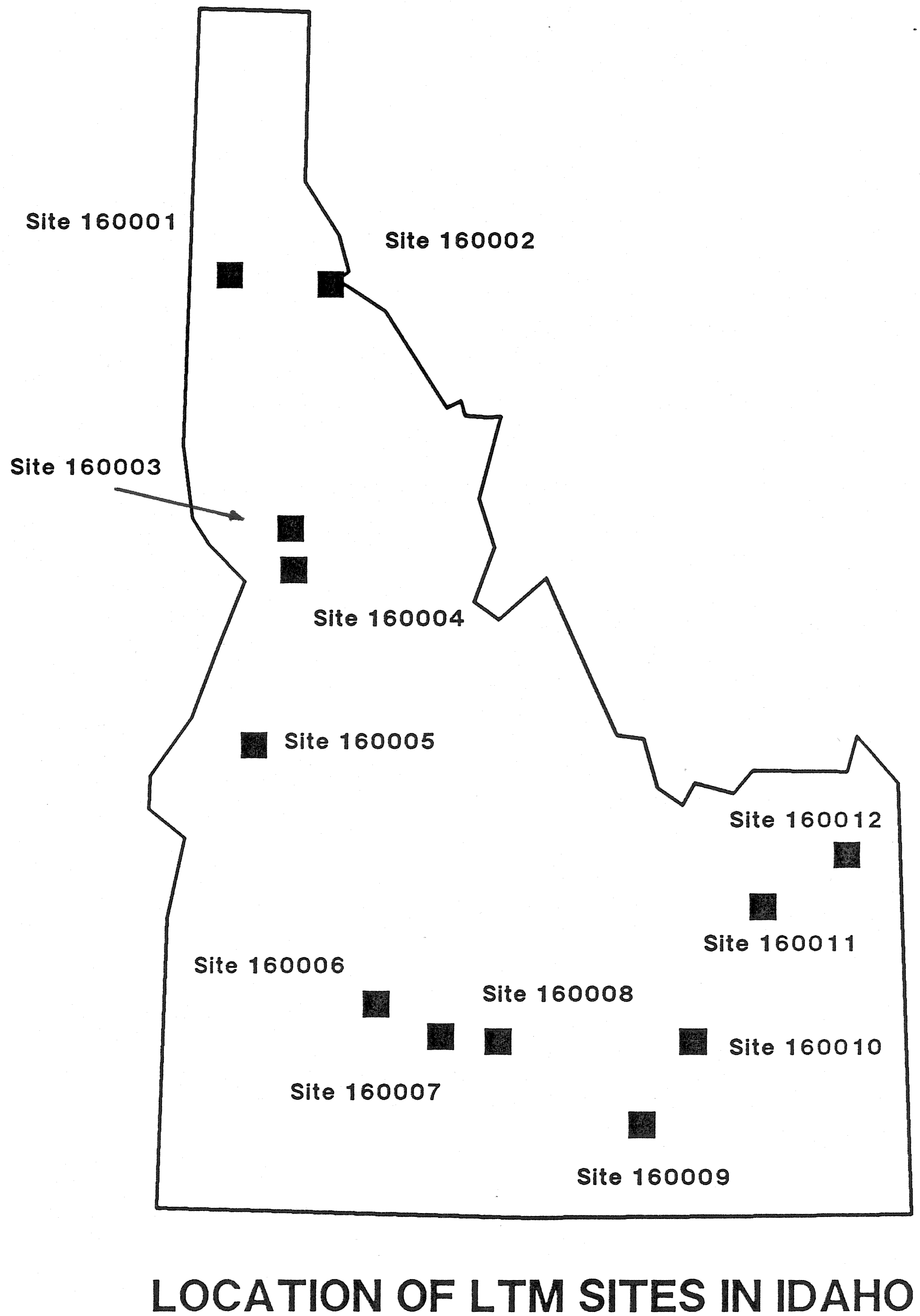


Figure 1, Location of LTM sites used in evalaution.

PROBLEM STATEMENT

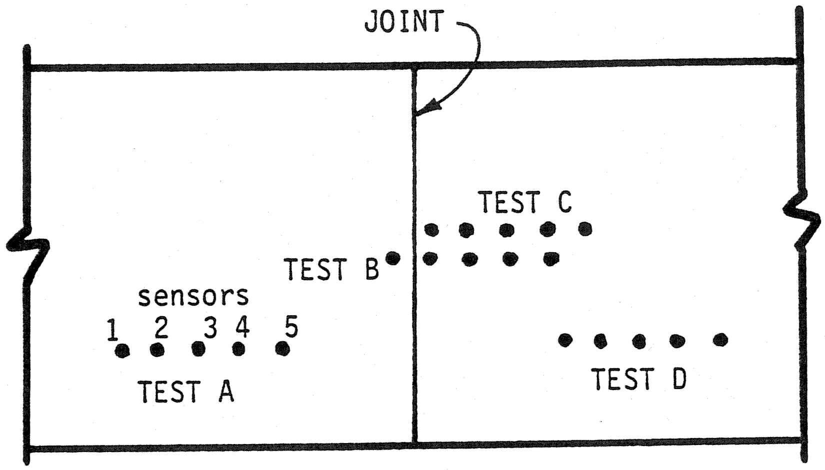
The intent of the proposed research was to evaluate any significant correlations between Dynaflect readings and pavement surface cracking for both portland cement concrete (PCC) and asphalt concrete (AC) pavements. The Long Term Pavement Monitoring Program (LTM) data, collected during the period February 1982 to August 1987, were made available for study.

The overall objective of this study was to determine the pertinent parameters for measuring the Structural Index (SI) for both PCC and AC pavements as related to past data measurements of deflection, cracking and other data associated with the variables. Correlations, if they exist, may allow the practical assessment of structural capacity and remaining useful life. Overlay design methods may also be developed on this basis. On the other hand, if there is no correlation between deflection and surface distress measurements, or there is no apparent need for a specific deflection measurement, then an assessment via correlation is not practical. not true

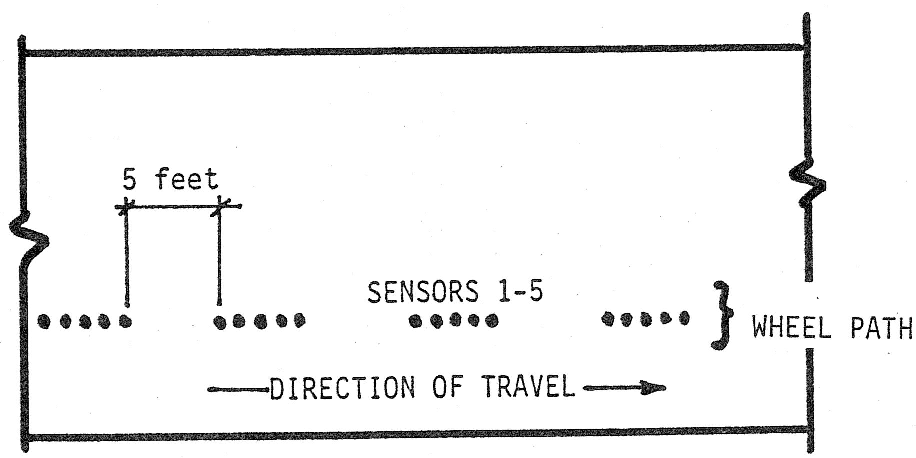
All deflection data for the LTM sites were generated with the Dynaflect device. The Dynaflect is a trailer-mounted, non destructive, pavement testing device. A sinusoidal vibrating load of 1000 lb, peak-to-peak amplitude, is applied to the pavement at a frequency of 8 Hz through 2 steel wheels spaced 20 in. apart. Peak-to-peak surface deflections are measured by five geophones sequentially spaced 12 in. apart, with the first geophone located midway between the loading wheels. The tests are performed at 4 locations, A through D, as shown in Figure 2.

SUMMARY OF PREVIOUS WORK

Previous results for this project for PCC pavements were presented in an interim report dated October 27, 1988. The analysis of LTM data for PCC pavements indicated a poor linear correlation between Dynaflect deflections and cracking index. The correlation coefficient, R^2, was only 0.16, thus implying that the linear analysis explains only 16% of the data. Also, the cracking index for PCC showed a general tendency to decline with time.



(a) Portland Cement Concrete (PCC)



(b) Asphalt Concrete

Figure 2, Sketch showing location of sensors and sequence of tests for the Dynaflect device.

Why LTM data showed only transverse crackings for AC pavements? There are also longitudinal crackings in the data base.

METHODOLOGY

The research leading to this report phase of the project consisted of the following main steps:

A. Inventory and entry of LTM data into a database

B. Development of cracking index model

C. Investigation of cracking index versus time

D. Investigation of Dynaflect data versus time

E. Regression and correlation analysis of Dynaflect data and cracking index.

sensitivity analysis?

Each of these main steps is described in detail in the following paragraphs.

The inventory phase for the AC study included extracting the pavement section information from the data base followed by a search of significant classes of pavement distress. The database records for the prevalent types of surface distress at the Idaho LTM test sites were checked for any obvious bias that may influence the correlation of surface deflection and cracking index.

A modification of the Pavement Condition Index (PCI) presented in FHWA/RD-81/080, "A Pavement Moisture Accelerated Distress (MAD) Identification System, Users Manual" was selected for incorporating the surface distress data (sheets 2,3 and 4) from the LTM study into a quantifiable and repeatable cracking index (The FHWA method was used to apply a system of deductions for various types and severity levels of pavement distress for both AC and PCC pavements). The LTM data showed longitudinal and transverse slab cracking for PCC pavements and only transverse cracking for AC pavements. The steps used for calculating the cracking index from the LTM data for a pavement subsection are outlined below:

1. Retrieve the data from the LTM data base at each site for longitudinal and/or transverse cracking distresses and severity levels of low, medium, and high. Organize the data by subsection and date.

2. The FHWA deduction curves are based upon a value of lineal feet of cracking per mile for PCC and lineal feet of cracking per 100 square feet for AC pavements. For a single PCC subsection (1/10 mile) then, it is necessary to multiply the lineal feet of each severity level and type by 10 to obtain the correct deduction value from the appropriate FHWA curve.

   For an AC subsection (1/10 mile), the total lineal feet per 1/10 mile reported was assumed to be distributed uniformly over the area of the lane and the lineal feet per 100 square feet determined.

3. The sum of the FHWA deductions is corrected for the number of severity levels and types using the Total Deduct Value curve. The resulting corrected deduction is subtracted from 100 and then divided by 0.05 to normalize it to the ITD cracking index scale of 0 to 5.

4. Steps 2 and 3 are repeated for each date within the data set for the subsection.

Examples of the above cracking index calculation procedures are presented in the Appendix. LTM data base files were exported from the original DBASE III+ format to the LOTUS 123 format for all calculation and graphing processes.

Limited value without temp correction

The raw Dynaflect data was extracted from the LTM data base in a manner similar to Step 1 above. The Dynaflect readings collected for the LTM study consisted of 4 separate tests in each subsection, identified by the letters A, B, C, and D as detailed in Figure 2. For a PCC pavement, tests B and C were performed near the joint. Data from tests at B were used to investigate cross-slab deflections.

For an AC pavement, tests at locations A, B, C, and D are measured in the first wheelpath of each lane, each reading separated by 5 feet 10 and then 20' in the direction of travel. Data were organized by subsection and date, and values at all four deflection test locations were averaged for the AC pavements. *

- Should not use raw deflection data of AC pavements in trying to correlate them with crackings. LTM data were collected in spring & fall each year from 82 - 85, and in spring 86 and 87. Since temperature has a significant effect on deflection, the deflection data should be temperature corrected (to standard temp. of 60°F) before employed in the regression analyses.

After generating the cracking index and Dynaflect files for each subsection of each site, changes in cracking index and Dynaflect readings as a function of time were investigated. This was done primarily as a rough visual filter of the data to check for gross anomalies, overall trends, or possible data entry errors. It was expected that cracking index would decline with time, and that Dynaflect readings would show a corresponding increase in deflection with time. Figures 3 and 4 show the relationship between calculated cracking index and time for AC sites. These plots show that the cracking index fluctuates with time and that it was always greater than 4.3. A cracking index of 5 is the best rating possible, so a cracking index of 4.3 indicates a pavement with very little surface cracking.

Figure 5 is a plot of Dynaflect deflections versus time for an AC site and shows the type of seasonal fluctuation of deflection encountered in AC deflection measurements. A similar plot for a PCC site is presented in the appendix. Should correlate spring & Fall defl separately

The final step consisted of a regression analysis to evaluate any correlation between the cracking index and Dynaflect deflections. The number of pairs used in the regression analysis for AC sites was 416 for lane 1 and 271 for lane 2. Figures 6 and 7 are typical scatter plots of the cracking index versus deflection data (lanes 1 and 2) for the AC sites. These scatter plots were reviewed for any possible trends in the data. Corresponding scatter plots for PCC sites were presented in the interim report and are reproduced in the appendix of this report. The AC scatter plots show the tendency of the data to cluster about cracking index values of 4.6 and 5.0. The clustering of data at a cracking index of 5.0 is attributed to the relatively small amount cracking reported for the AC sections.

The deflection data were viewed from one additional perspective. Three PCC sites (160001, 160002, and 160006) were reviewed for cross-slab deflections under the Dynaflect tests. The LTM Dynaflect test location B (see Figure 2), in which the first and second sensors are located at opposite sides of the joint, was used to determine if any significantly obvious joint load transfer problems exist at these sites.

If only transverse crackings of AC pavements were available in the LTM data base, then trying to correlate them to deflection data is just a waste of time. I believe that most of the transverse crackings in LTM AC pavements are thermal crackings that have nothing to do with the pavement structural conditions.

DISCUSSION OF RESULTS

The cracking index versus time plots (Figures 3 and 4; and appendix) show that the cracking index does not decline uniformly with time, but fluctuates with time. The plots of Dynaflect versus time display the seasonal variation (high deflections in spring, low deflections in ~~winter~~ fall) recorded in the deflection readings. Scatter plots of cracking index versus Dynaflect deflection (Figures 6 and 7; and appendix) indicate that linear regression models explain less than 16% of the data points.

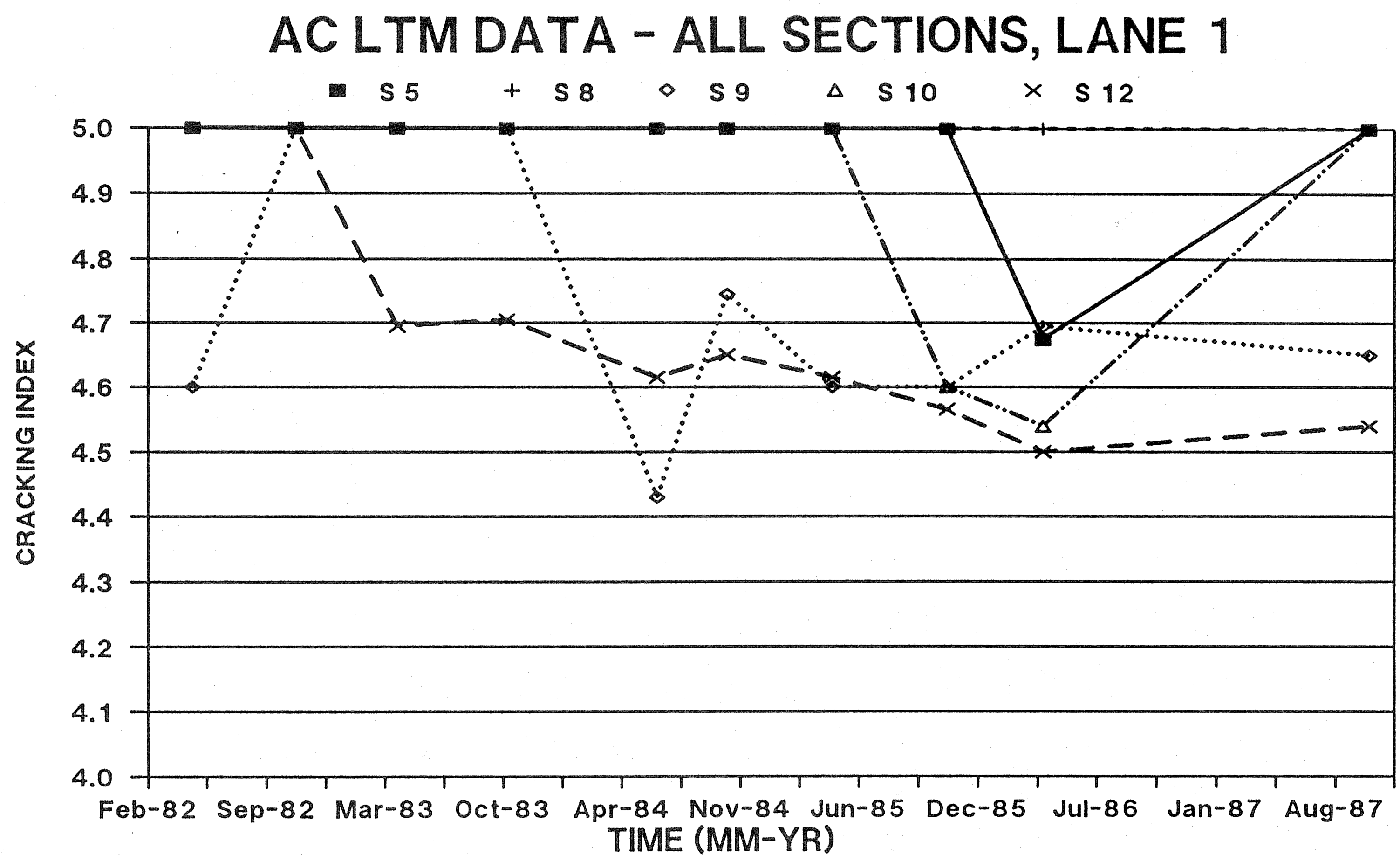
Other regression models (logarithmic, exponential, and power) were found to have even lower correlation values. The correlation is generally better for the sensor 1 readings than for the other sensors (2,3,4, and 5). The scatter plots reveal a clustering of the data points around a cracking index of 4.6 for the AC sites. The scatter plots for the PCC sites had a wider scatter than the AC sites and appear to be more dense around a cracking index of 4.3. The results for PCC and AC sites are discussed separately, below.

PCC Sites

The cracking index, as calculated by the FHWA method described earlier, exhibits a slight tendency to decline with time and appears to oscillate about some average value. Cracking index calculations for the given PCC test sites ranged from 3.0 to 5.0. The average cracking index for lanes 1 and 2 were 4.6 and 4.9, respectively. The overall range of the Dynaflect deflections for sensor 1 is from 0.01 to 1.98 mils and the average deflection is 0.42 mils. at what location

The scatter plots (appendix) displayed a wide variation in the data, as confirmed by the statistical regression analysis. Of the 4 types of regression curve fitting techniques used (linear, logarithmic, exponential, and power), the linear fit gave the highest calculated coefficient of determination, R^2. The highest R^2 value thus calculated was 0.16 for PCC sites. These values are considered poor for prediction purposes.

discussions & conclusions re rate of change & sensitivity need to be more ~~[illegible]~~ definite



do dates indicate date of test or relate to tick MARKS on scale what is scale

Figure 3, Plot of cracking index and time for asphalt concrete sites.
(sites are referenced as: S5-- site 160005, S8-- site 160008, etc.)

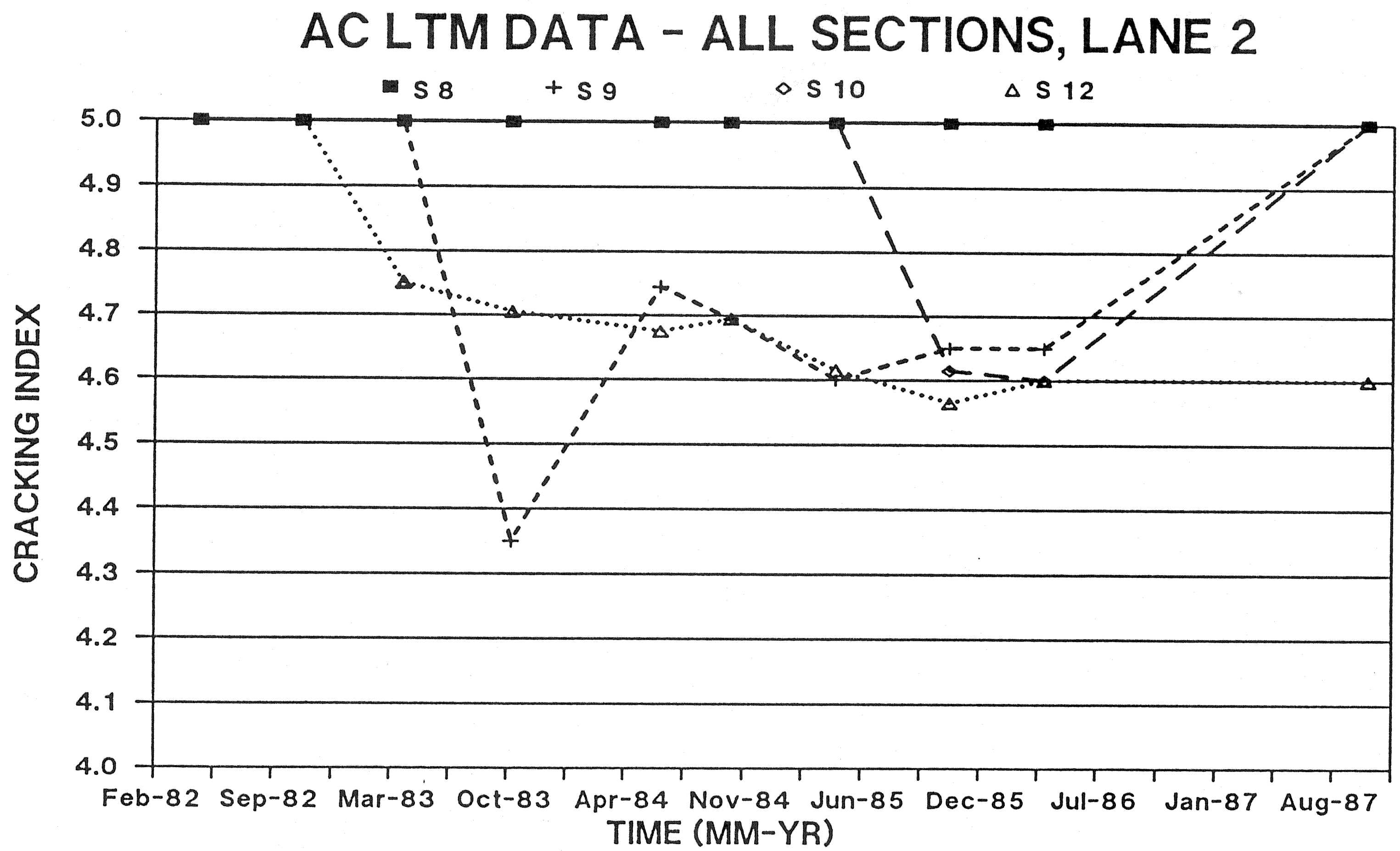
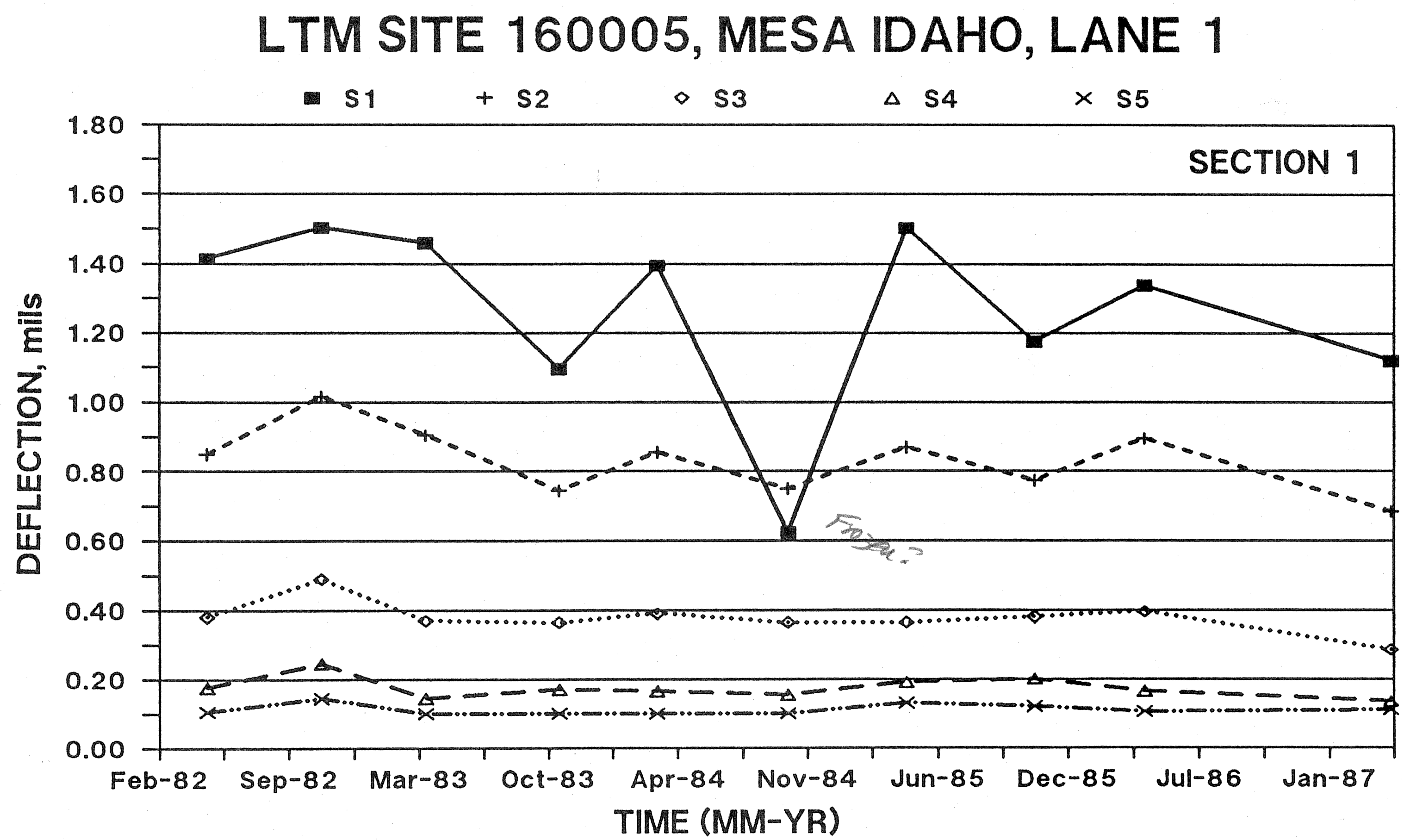


Figure 4, Plot of cracking index and time for asphalt concrete sites, Lane 2.
(sites are referenced as: S8-- site 160008, S9-- site 160009, etc.)

SAME



Same.

Figure 5, Plot of Dynaflect deflections and time.
(Sensors 1,2,3,4 & 5 are referenced as S1, S2..S5)

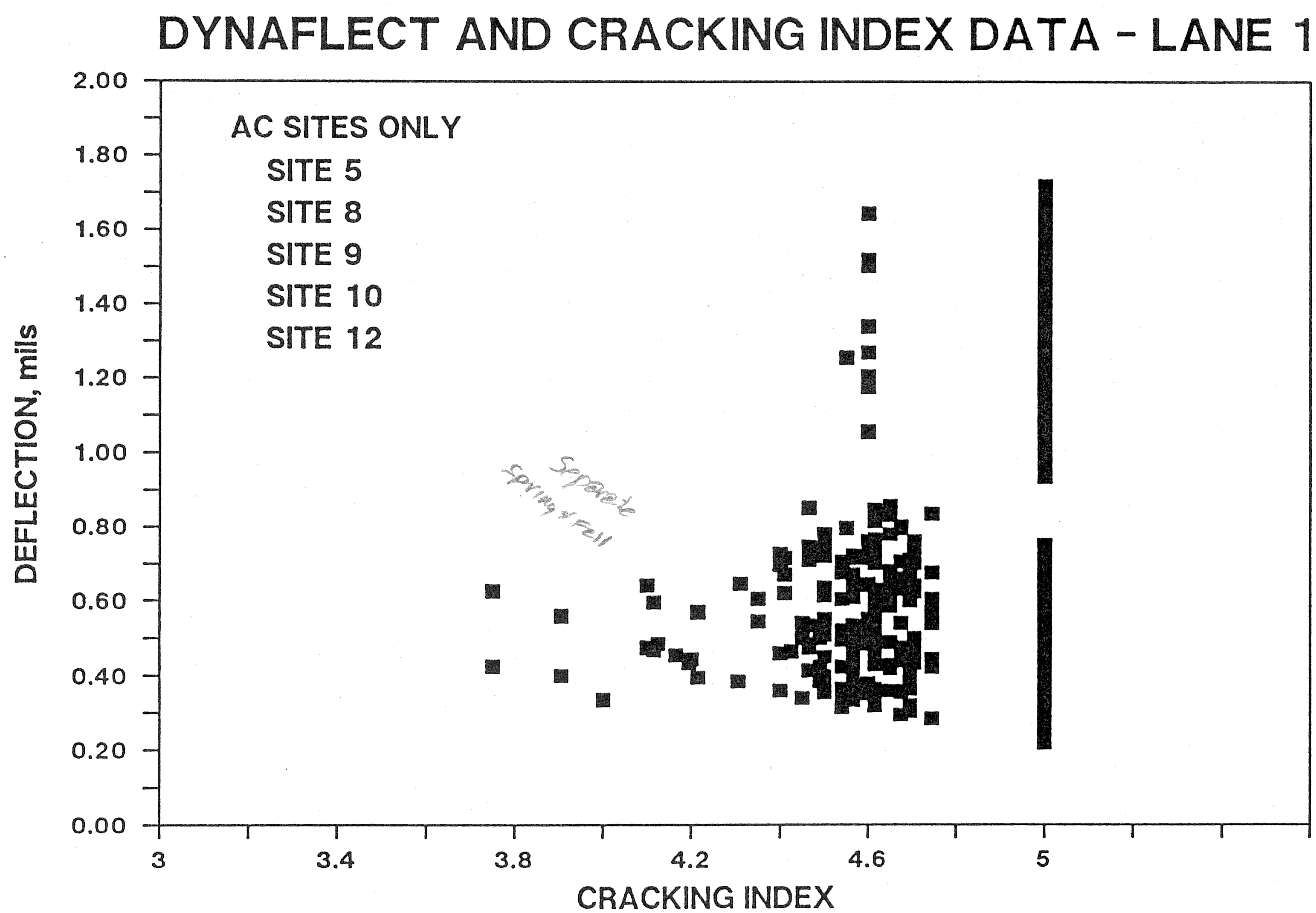


Figure 6, Scatterplot of Dynaflect deflections and cracking index for lane 1.
(note the clustering of data at CI = 5)

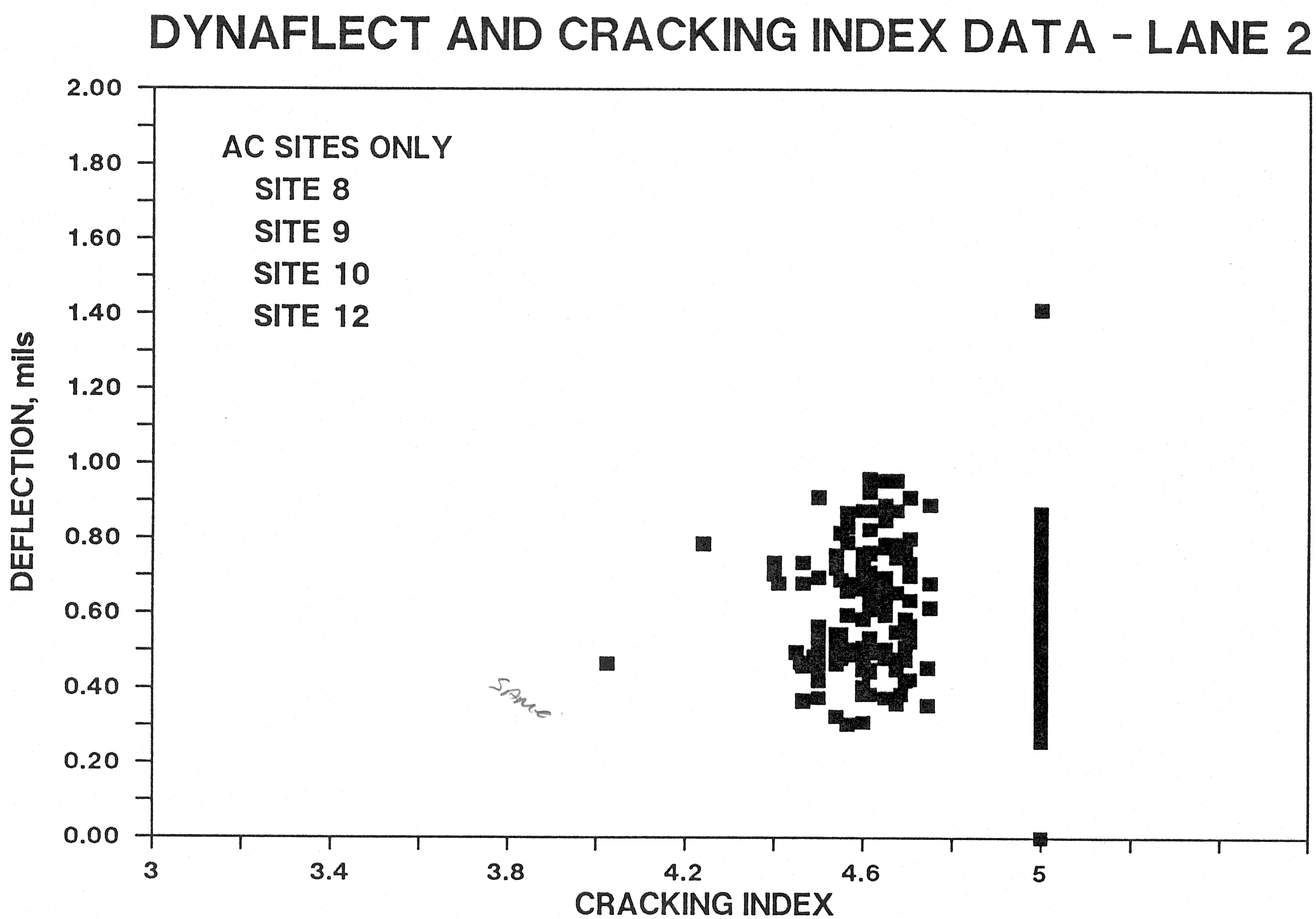


Figure 7, Scatterplot of Dynaflect deflections and cracking index for lane 2. (note the clustering of data at CI = 5)

Most of PCC sections showed poor joint load transfers in spring when the temperature was low. However, deflection data in fall, when temp. was high, indicated that the joint load transfer capabilities were a lot better than those measured in spring.

A limited investigation of the cross-slab deflections at sites 160001, 160002 and 160006 indicated that the difference between sensor 1 and sensor 2 readings for test location B (Figure 2) tended to be very small, which means a good load transfer across the joint. Some exceptions were observed for site 160006, in which the sensor 1 deflection was 2 to 3 times the sensor 2 deflection. This condition indicates poor joint load transfer.

so? temperature effect?

AC Sites

Of the different cracking types considered important to the cracking index (transverse, longitudinal, alligator, and block), only transverse cracking data had been reported for the LTM AC sites, and thus was the only type used in the cracking index calculations. The data for Site 160004 revealed no transverse cracking. For this site, the cracking index would have been a maximum value of 5.0, and including this data in the regression analysis might bias any possible correlation. Thus, site 160004 was excluded from the regression analysis. Only sites 160008,9,10,12 have two lanes of data reported. The minimum cracking index for any site was 4.3, and the overall average cracking index for both lanes was 4.8.

The cracking index, computed using the modified FHWA method, is presented in Figures 6 and 7 along with the Dynaflect deflection data. The plots display a clustering of the data about a cracking index of 4.6. The statistical regression analysis confirmed the general lack of a trend. The highest calculated R^2 value was 0.09 for AC sites using the linear regression model. These values are also considered poor for prediction purposes.

The evaluations of the cracking index versus Dynaflect measurements for AC pavements failed to reveal any reliable correlation between cracking index and deflection. The maximum reported Dynaflect sensor 1 deflection was 1.72 mils, which is in the same range as the maximum reported mid-slab deflection for the PCC pavements and it appears to be the opposite of what may be expected intuitively.

PRACTICAL IMPLICATIONS

Analysis of the LTM data using the methodology described above indicates that there is a poor correlation between the dynaflect deflections and the cracking index for both flexible and rigid pavements. The high cracking index suggests that more data on cracking at sites having lower cracking index values are needed. The use of only transverse cracking was necessary because it was the only available cracking data for AC pavements. However, in our opinion, transverse cracking is more a function of thermal effects in flexible pavements and may not correlate with deflections induced by surface devices.

will !

Any visual cracking index method used on an AC pavement may not properly assess the true time dependent wheel load associated cracking which exists in the pavement, but may not yet be evident at the surface. The cracking used to determine the cracking index for an AC pavement must therefore be supplemented by deflections produced by test devices.

The maximum Dynaflect deflections for AC sections at sensor 1 were roughly the same as for the PCC sections. The flexible pavements would have been expected to deflect more under the Dynaflect than the rigid pavements, but the data shows otherwise. This result suggests that the deflection values in a range of less than 2 mils are suspect because of inherent variabilities in equipment, operation and pavement material's response at minute strains resulting from very low surface deflections. Dynaflect deflections might not provide significant and reliable deflections in both PCC and AC pavements at LTM sites in Idaho. This raises the question of how much deflection would be significant and reliable. More work is required to investigate the reliability of the equipment and instrumentation used in performing Dynaflect tests.

conclusions
re rate of change
& sensitivity

RECOMMENDATIONS FOR FUTURE WORK

In conducting this preliminary evaluation of the LTM data collected by the Idaho Transportation Department, the following limitations were noted :

1. There were no reliable correlations between cracking index and Dynaflect measurements, based on the limited amount of LTM data. A further study of non-LTM data collected in the state of Idaho is recommended if useful correlations between Dynaflect values and cracking index are to be used in evaluating pavement integrity.

2. During a review of the LTM data, and discussions with ITD personnel, it was apparent that the <u>same</u> locations were not sampled with the Dynaflect device every time. This leads to sampling errors and further complicates the evaluation procedures. It is recommended that ITD develop a robust sampling technique based on classical statistical methods that are commonly used for quality control in manufacturing industries. Additionally, such a scheme could be selected with a view to maximizing the cost-benefit ratio related to the number of locations selected for sampling.

3. The reported measurements for the Dynaflect device were generally very small. It is important that field operators should be made aware of the anticipated magnitude of deflections that must be measured in order to avoid errors due to :
   - (a) instrument accuracy,
   - (b) reliability of measuring instruments,
   - (c) ability of the device to actually stress the pavement section.

4. Although there was very little cracking associated with wheel loads in the AC pavements in the LTM data, the use of deflections on asphalt concrete pavements (i.e. flexible) appears relevant for indicating time dependent degradation. In these pavements, crack propagation towards the surface is time dependent. However, the rate of surface cracking will strongly depend on the magnitude and repetition rate of

the applied wheel loads and the structural thickness of the pavement. Thus, increasing deflections should be reported as more cracks develop at the bottom of the surface layer and then propagate towards the surface. These "bottom" cracks will not be visible at the surface and thus will not be included in the assessment of cracking index. Thus deflections will have to be measured and correlated with "bottom" cracking to establish a correlation with the structural index.

5. Dynaflect deflections, reported for the PCC pavements, were measured on the slabs as well as in the vicinity of the joints. In PCC pavement slabs (i.e. rigid), crack propagation may be more spontaneous than in AC pavements so that the cracking intensity observed at the surface will be similar to the one found to exist at the bottom of the rigid layer. Therefore, a visual cracking index should suffice as a time dependent indicator of the structural index for the slab portion of PCC pavements.

6. Deflection measurements should be made at the PCC joints to evaluate the inter-slab load transfer. The rate of decrease in the load transfer with time should provide useful information about the integrity of the PCC pavement. However, the type of deflection measuring device (a current device or one developed in the future) is open to suggestion and further work will be required in order to make a rational decision.

7. On the basis of deflection measurements at the PCC joints, equal slab deflections on each side of the joint for a wheel-in-motion would indicate excellent load transfer. A permanent displacement, unrelated to the wheel-in-motion, would suggest faulting caused by erosion. It would be desirable if a common deflection device could be developed and applied for these cases. This would lead to the assessment of a joint capacity index which may be used to assign the appropriate maintenance repairs.

APPENDIX

EXAMPLE CRACKING INDEX CALCULATION
USING THE METHOD DETAILED IN FHWA/RD-81/080
AND ADAPTED FOR USE WITH THE LTM STUDY DATA

STEP 1: Organize the data by subsection and date as below:

LTM FILE MJDIST FOR SITE 160006 FOR SECTIONS HAVING CRACKING DISTRESS

ST_SITE= 160006 JD_LANE= 1 JD_SECT= 00

JD_DATE		042782	101382	041483	101283	042384	092084	041185	102585	042186	100887
LOTUS	TIME	30068	30237	30420	30601	30795	30945	31148	31345	31523	32058
JLCR_L		9	13	13	14	16	10	10	19	15	13
JLCR_M		0	0	0	0	0	15	13	0	13	13
JLCR_H		0	0	0	0	0	0	0	0	0	0
JTCR_L		78	117	128	116	127	87	104	56	55	80
JTCR_M		0	0	0	0	0	60	60	84	85	60
JTCR_H		0	0	0	0	0	0	0	12	12	0
TOTAL CRACKING, FT		87	130	141	130	143	172	187	171	180	166

STEP 2A: Multiply the above values by 10.

LTM FILE MJDIST FOR SITE 160006 FOR SECTIONS HAVING CRACKING DISTRESS
LINEAL FEET OF CRACKING X 10

ST_SITE= 160006 JD_LANE= 1 JD_SECT= 00

JD_DATE		042782	101382	041483	101283	042384	092084	041185	102585	042186	100887
LOTUS	TIME	30068	30237	30420	30601	30795	30945	31148	31345	31523	32058
JLCR_L		90	130	130	140	160	100	100	190	150	130
JLCR_M		0	0	0	0	0	150	130	0	130	130
JLCR_H		0	0	0	0	0	0	0	0	0	0
JTCR_L		780	1170	1280	1160	1270	870	1040	560	550	800
JTCR_M		0	0	0	0	0	600	600	840	850	600
JTCR_H		0	0	0	0	0	0	0	120	120	0
	TOTALS	870	1300	1410	1300	1430	1720	1870	1710	1800	1660

STEP 2B: Obtain deduction value appropriate to severity level and crack type from FHWA deduct curves. Use curve A29 for JLCR_L,M,H and curve A40 for JTCR_L,M,H values.

LTM FILE MJDIST FOR SITE 160006 FOR SECTIONS HAVING CRACKING DISTRESS
FHWA DEDUCTS

ST_SITE= 160006   JD_LANE= 1   JD_SECT= 00

JD_DATE		042782	101382	041483	101283	042384	092084	041185	102585	042186	100887
LOTUS	TIME	30068	30237	30420	30601	30795	30945	31148	31345	31523	32058
JLCR_L		4	4	4	4	4	4	4	5	4	4
JLCR_M		0	0	0	0	0	8	7	0	7	7
JLCR_H		0	0	0	0	0	0	0	0	0	0
JTCR_L		0	0	0	0	0	0	0	0	0	0
JTCR_M		0	0	0	0	0	20	20	25	25	20
JTCR_H		0	0	0	0	0	0	0	13	13	0
TOTAL DEDUCTS		4	4	4	4	4	32	31	43	49	31

STEP 3: Apply correction to deductions using total deduct curve A2. For any given subsection, q is the total number of individual deduct values which are greater than 5. The total deduct value is the sum of the individual deduct values greater than 5. Enter curve A2 with known value of q and total deduct value, and read the corrected deduct value from the ordinate.

LTM FILE MJDIST FOR SITE 160006 FOR SECTIONS HAVING CRACKING DISTRESS
FHWA DEDUCTS AND CRACKING INDEX CALCULATIONS

ST_SITE= 160006   JD_LANE= 1   JD_SECT= 00

JD_DATE		042782	101382	041483	101283	042384	092084	041185	102585	042186	100887
LOTUS	TIME	30068	30237	30420	30601	30795	30945	31148	31345	31523	32058
JLCR_L		4	4	4	4	4	4	4	5	4	4
JLCR_M		0	0	0	0	0	8	7	0	7	7
JLCR_H		0	0	0	0	0	0	0	0	0	0
JTCR_L		0	0	0	0	0	0	0	0	0	0
JTCR_M		0	0	0	0	0	20	20	25	25	20
JTCR_H		0	0	0	0	0	0	0	13	13	0
TOTAL DEDUCTS		4	4	4	4	4	32	31	43	49	31
"q"		0	0	0	0	0	2	2	2	3	2
CORRECTED DEDUCTS		0	0	0	0	0	18	18	24	20	17
CRACKING INDEX		5.0	5.0	5.0	5.0	5.0	4.1	4.1	3.8	4.0	4.2

CRACKING INDEX = (100 - CORRECTED DEDUCTS)*0.05

STEP 4: Repeat steps 2 and 3 for each date within the data set for the subsection.

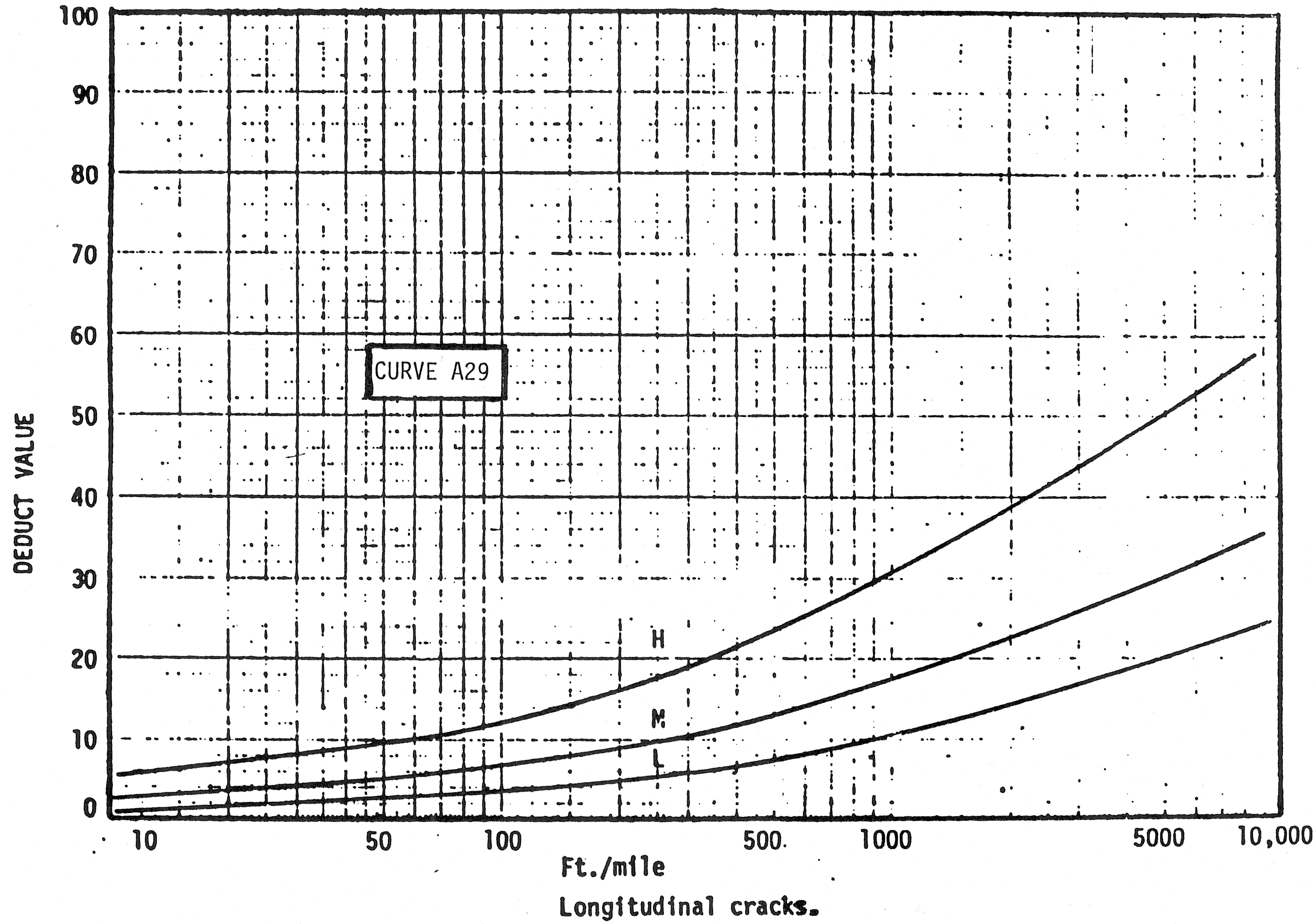


Figure A1, FHWA Deduct Curves for PCC Longidudinal Cracking.
(Curve A29)

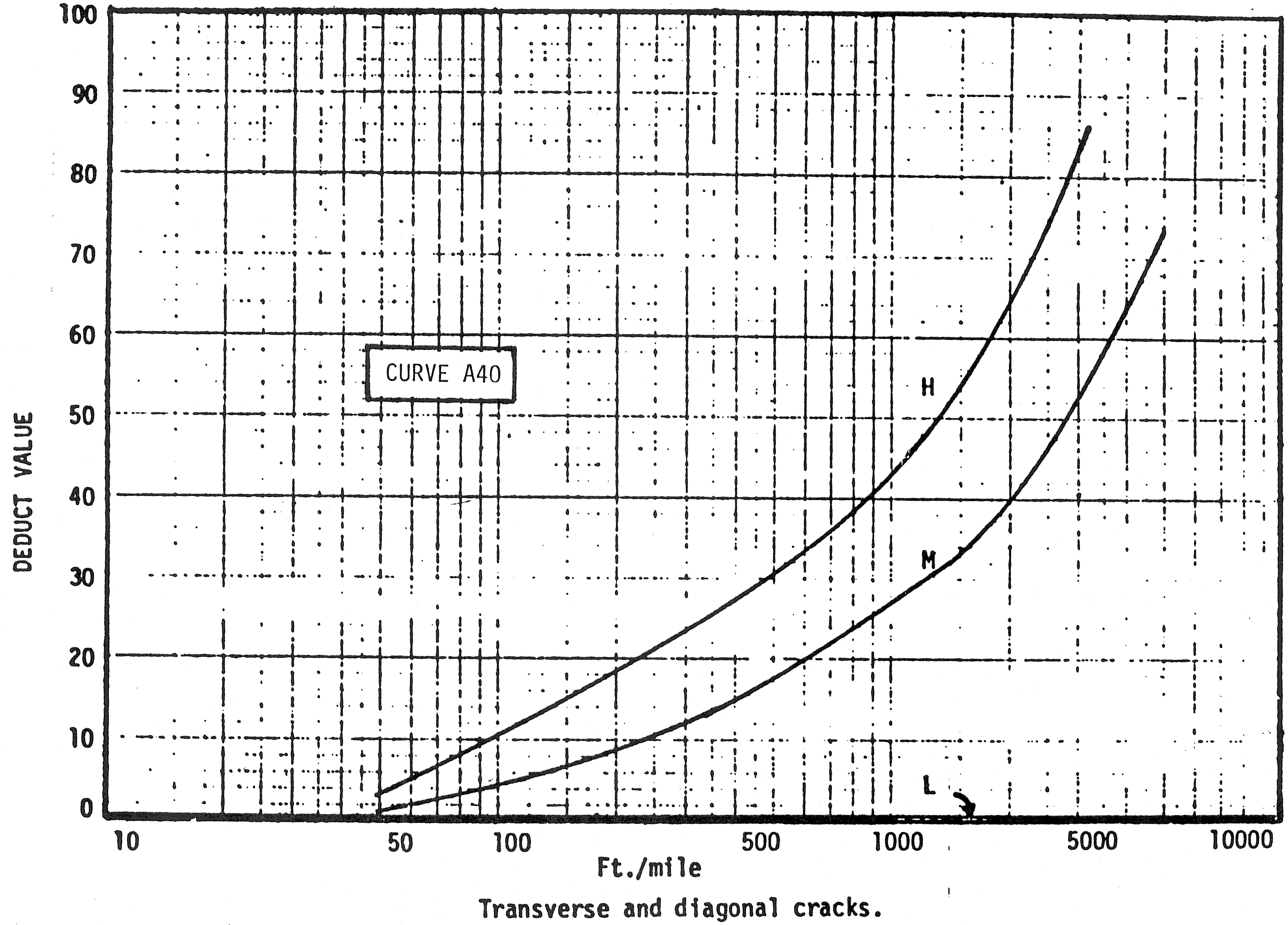


Figure A2, FHWA Deduct Curves for PCC Transverse and Diagonal Cracking (Curve A40)

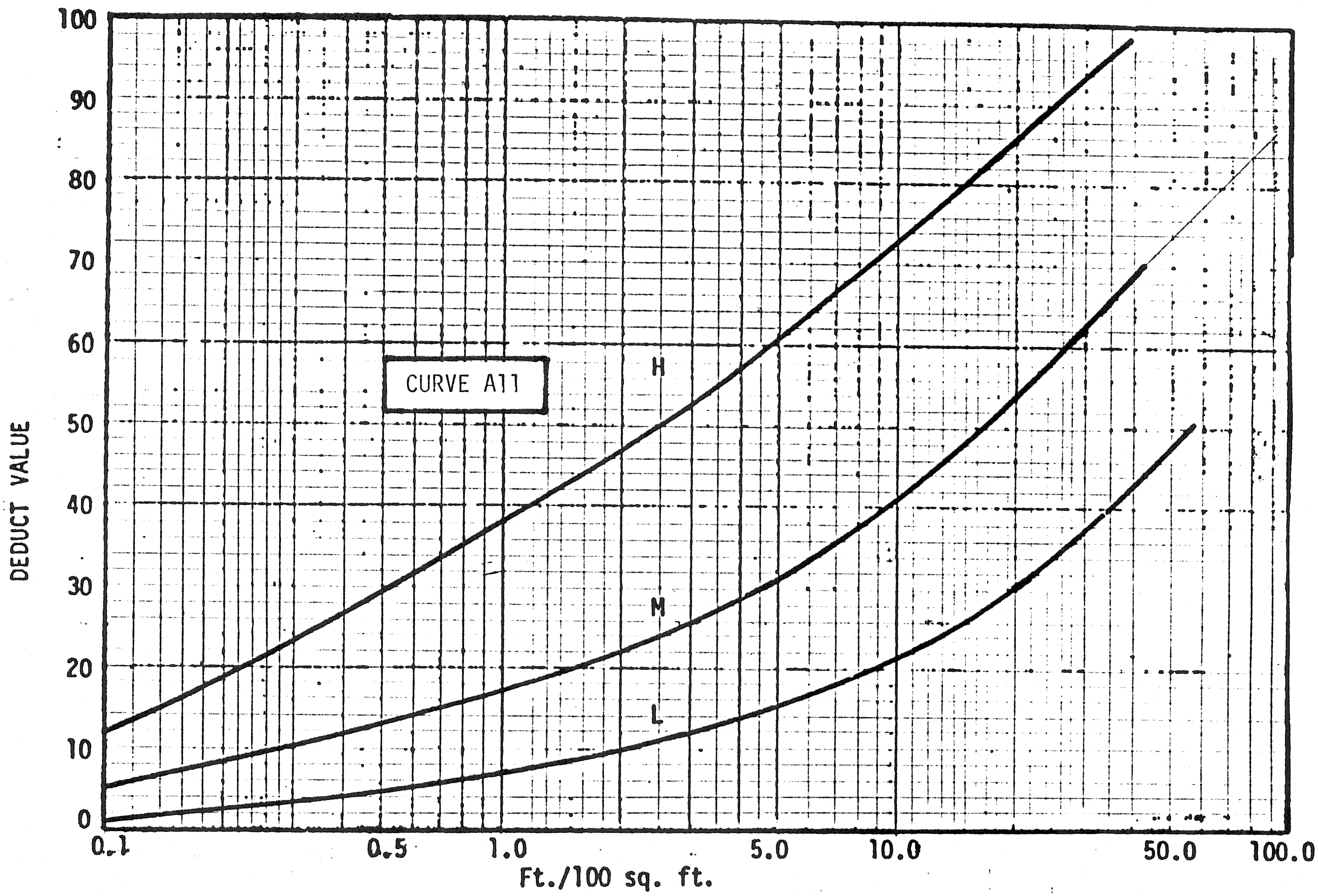


Figure A3, FHWA Deduct Curves for AC Transverse and Longitudinal Cracking.
(Curve A11)

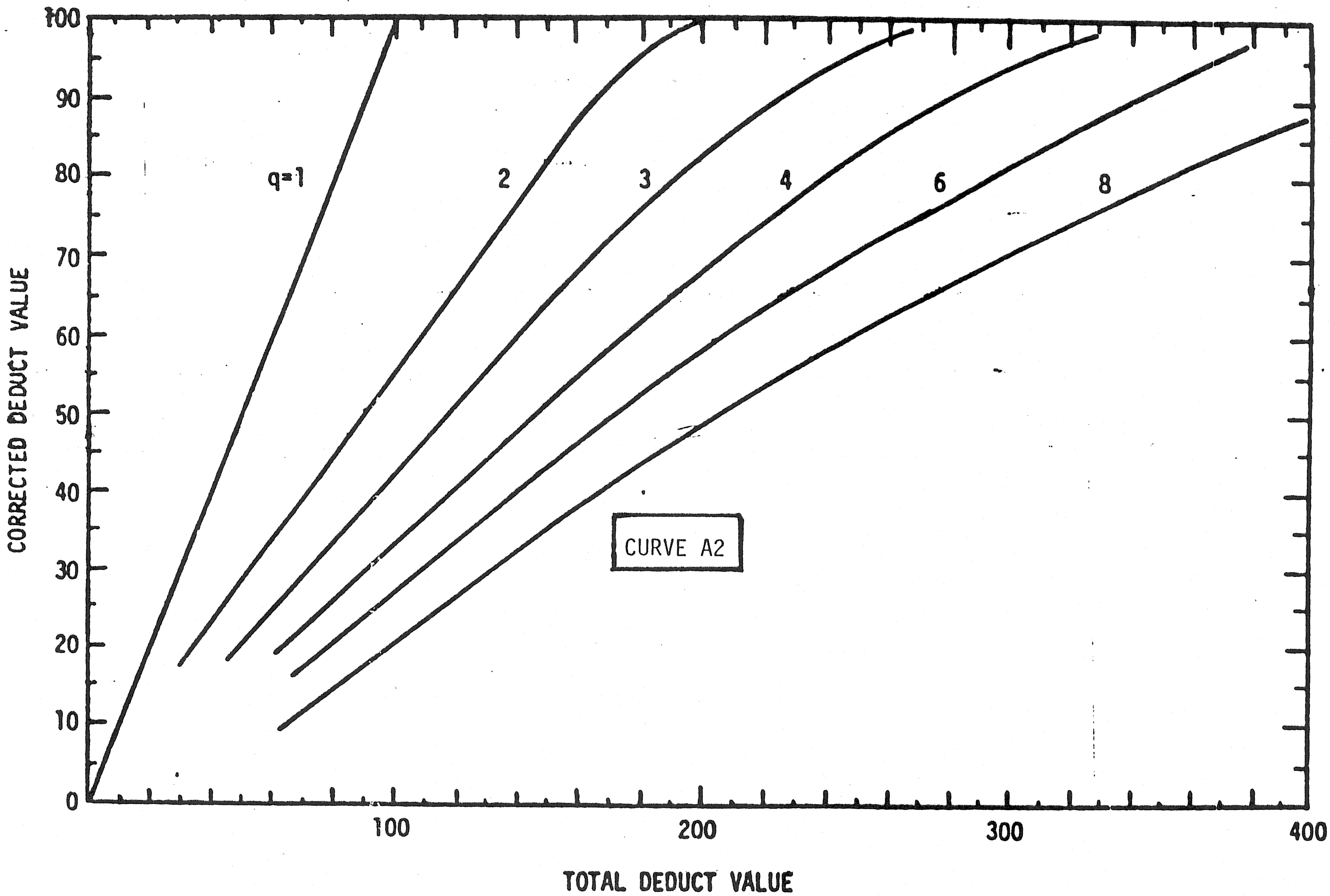


Figure A4, FHWA Corrected Deduct Value Curves Used for Both AC and PCC Pavement Cracking Types. (Curve A2)

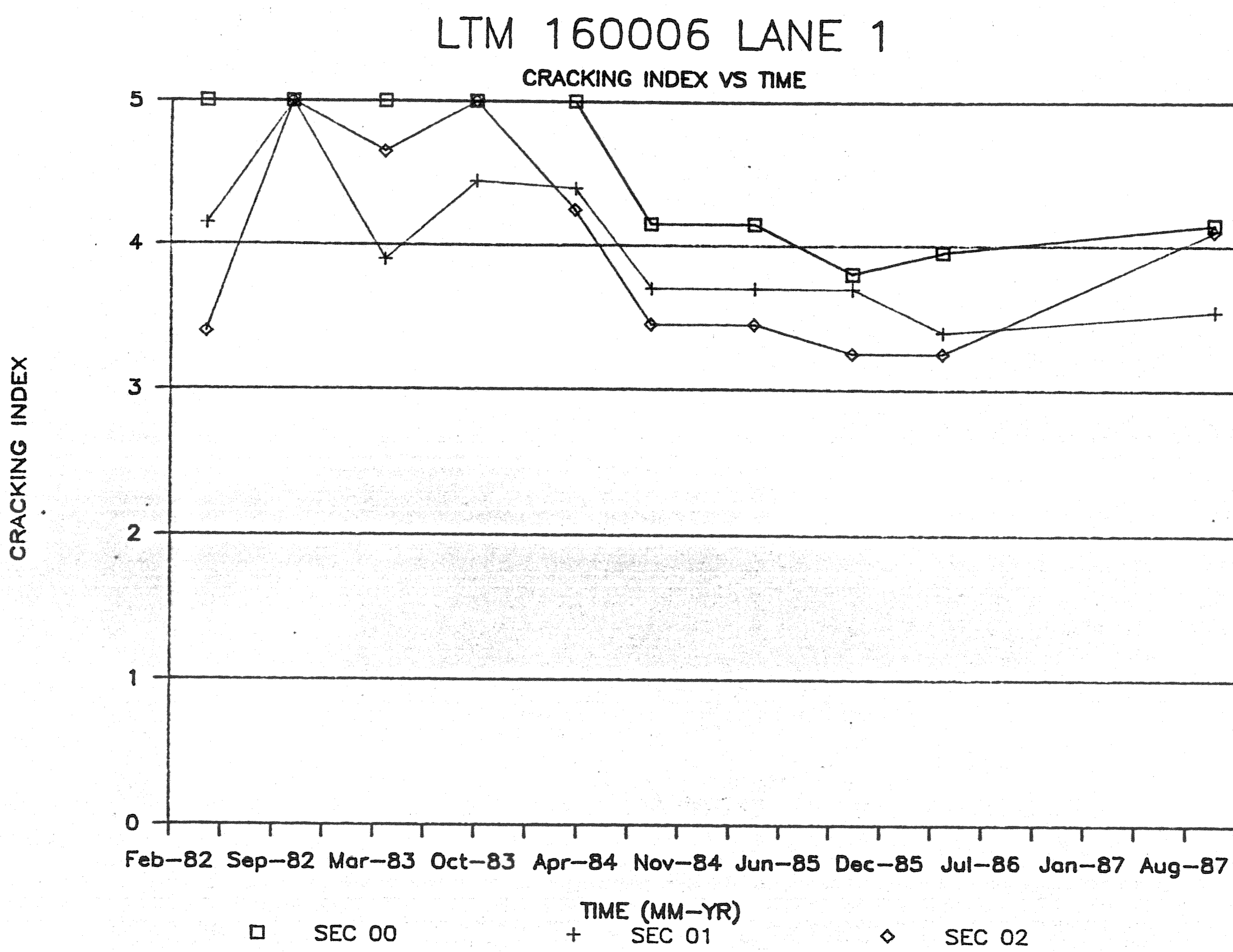


Figure A5, Plot of Cracking Index and Time for portland cement concrete Site 160006 at Mountain Home, Idaho, Lane 1, Subsections 0,1, and 2.

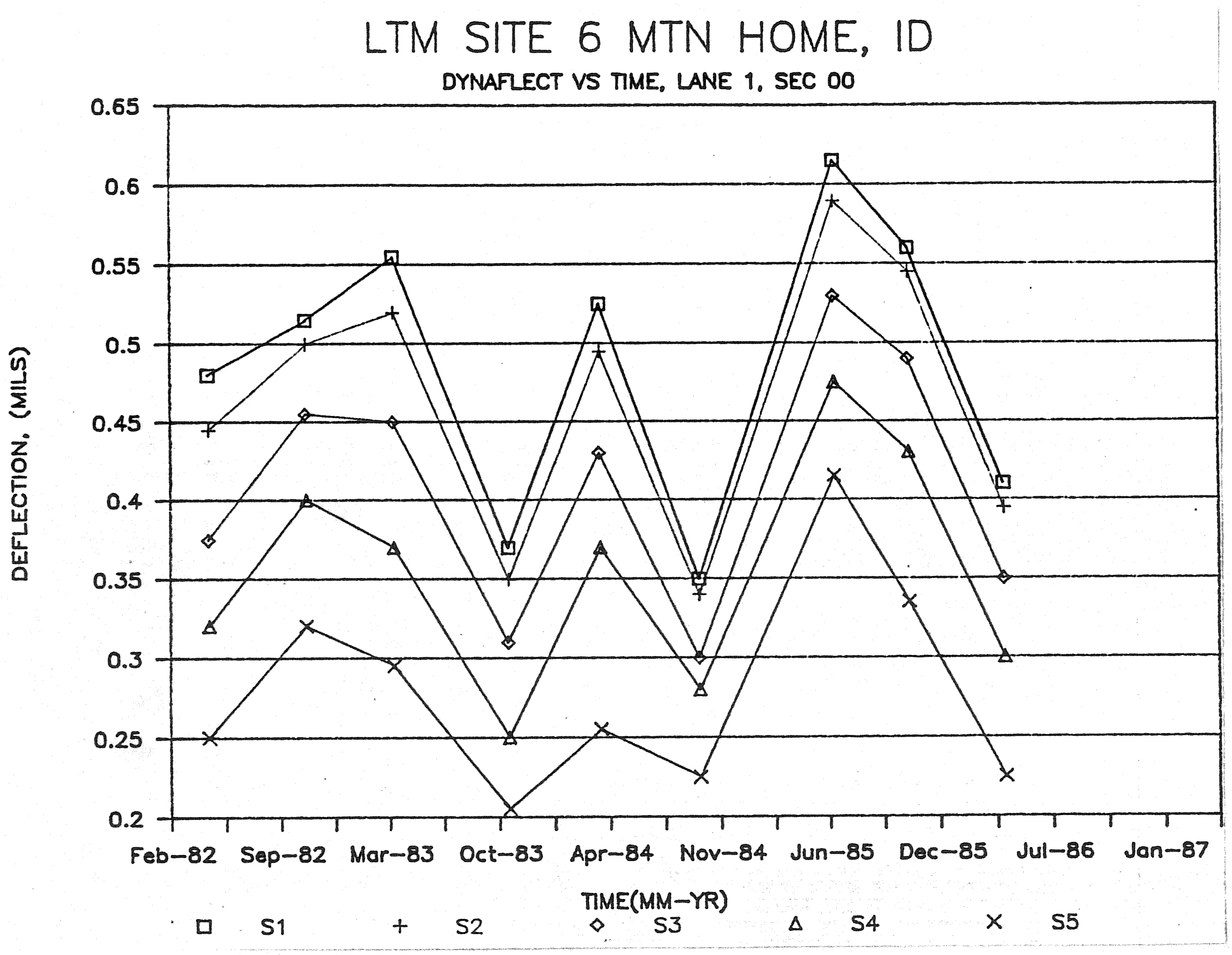


Figure A6, Plot of Dynaflect Deflections and Time for portland cement concrete Site k60006 at Mountain Home, Idaho, Lane 1, Subsection 0. (Sensors 1,2,3,4 & 5 are referenced as S1, S2...S5)

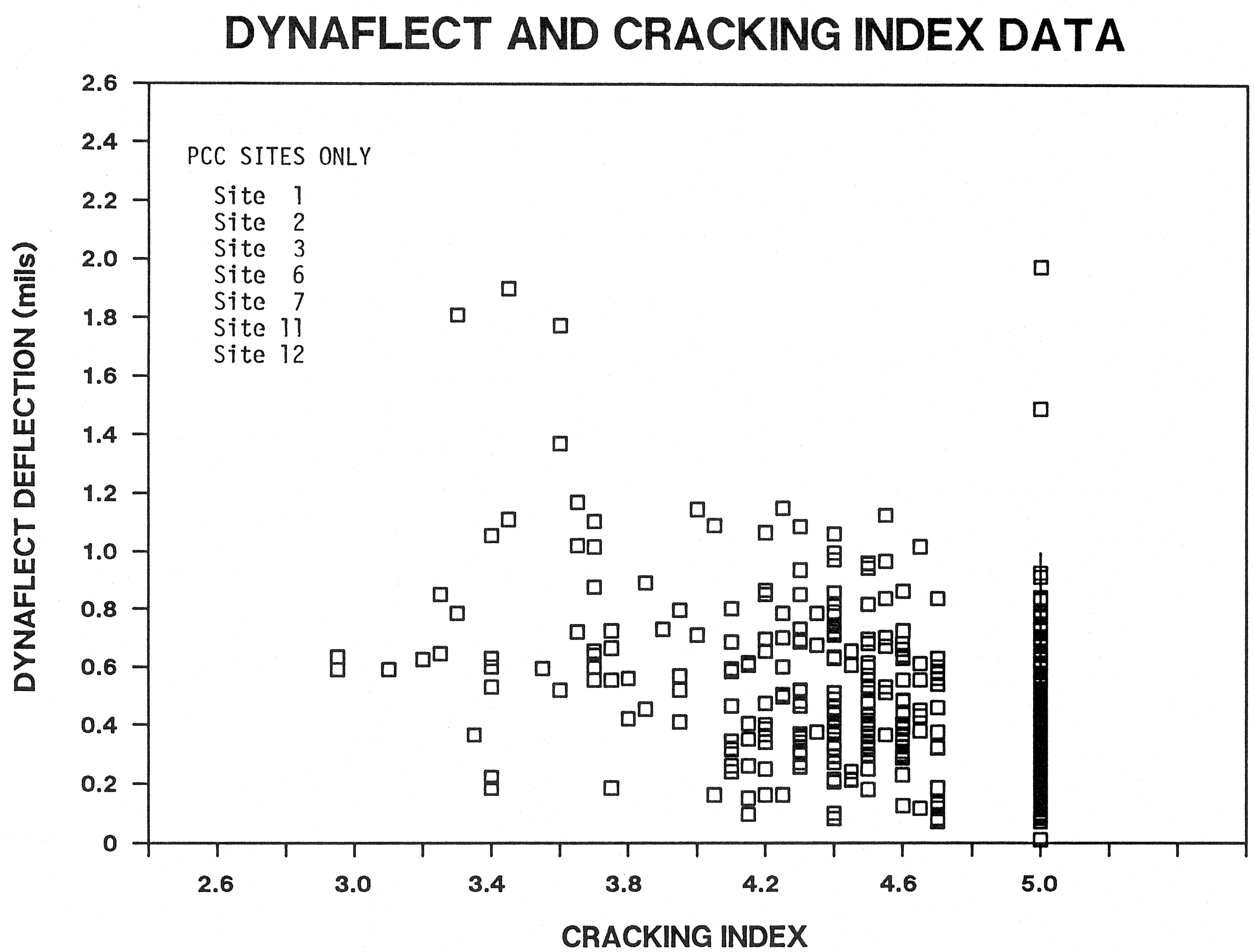


Figure A7, Scatterplot of Dynaflect deflections and cracking Index for lane 1. (note the clustering of data at CI = 5)

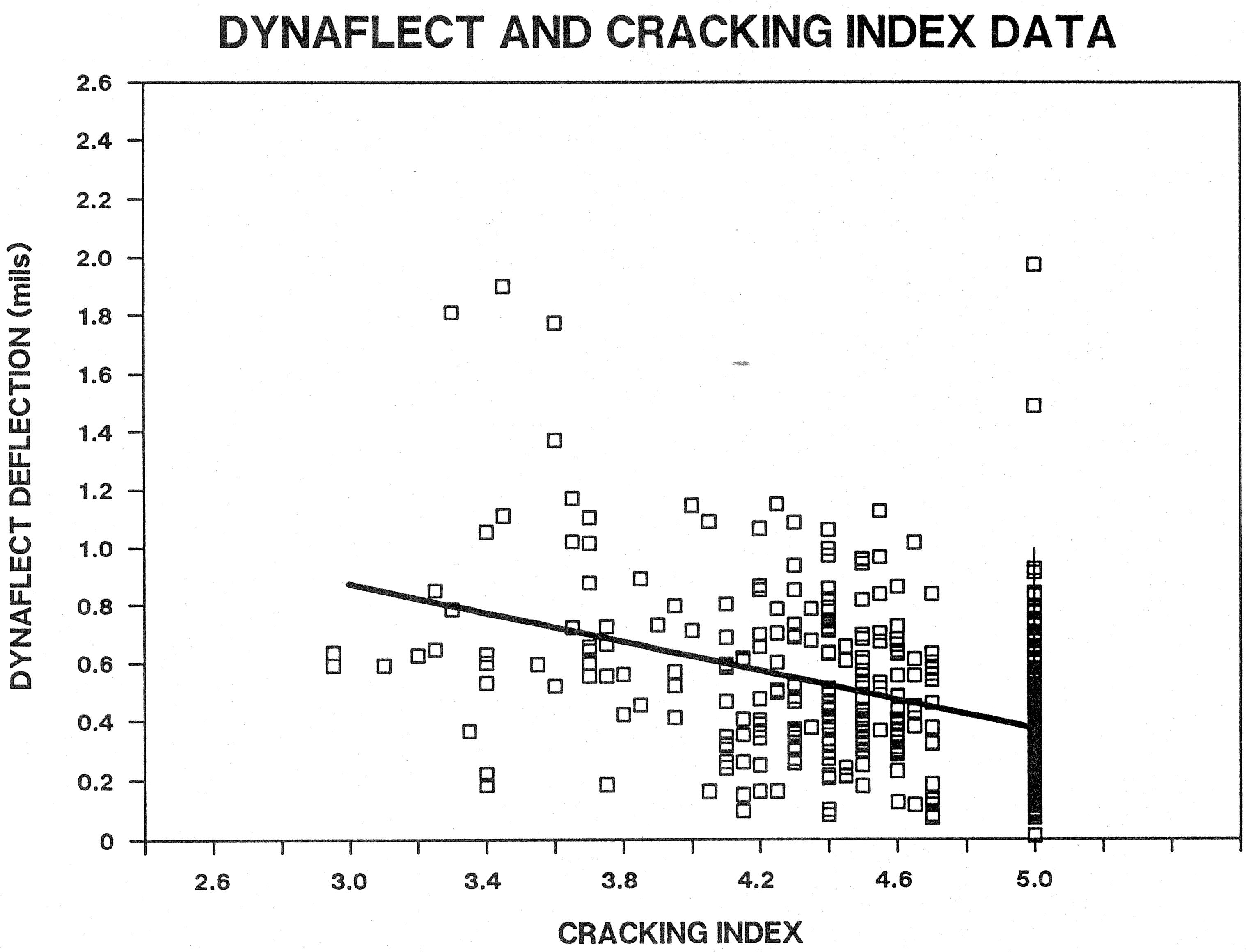


Figure A8, Scatterplot of Dynaflect deflections and cracking index for lane 1. (note that plotted linear regression line explains less than 16% of the data points)